

MICROSHRINK TENSILE PROPERTIES AND THE DETECTION OF
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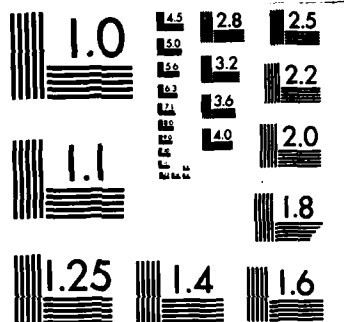
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MICROSHRINK, TENSILE PROPERTIES, AND THE DETECTION OF MICROSHRINK

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PERRY R. SMOOT
PROTOTYPE DEVELOPMENT DIVISION

November 1984

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ABSTRACT

The unknown effects of microshrink on the tensile properties of cast nickel-base alloys were investigated. The objectives of this investigation were to study the effect of microshrink on the tensile properties of alloy 713C and to find nondestructive methods of detecting microshrink at any significant level. Alloy bars were cast, the microshrinkage was measured metallographically, and tensile tests were run at 1000°F. A large number of sources were searched for information on methods to detect microshrink.

Within the range of 2.5% to 9%, measured in the local area having the greatest amount present, microshrink did not have any significant effect on tensile properties. A number of methods to detect microshrink nondestructively were found, but those other than conventional X-ray radiography would require development. The effect of microshrink on fatigue and creep properties was not investigated. Consideration should be given to making such an investigation of these effects. *Keywords:*

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HISTORICAL BACKGROUND

This research was undertaken as an outgrowth of an investigation of a gas turbine blade failure in which the blade airfoil separated from the root end during an engine overspeed condition. This blade was found to contain microshrink.¹ Although the maximum size of the microshrink was 0.035 inch and the amount of microshrink on the fracture surface relative to the total fracture surface area appeared significant,¹ the effect of microshrink on mechanical properties was not known. This work was undertaken, therefore, to investigate the effect of microshrink on tensile properties at 1000°F (the approximate temperature in the fracture region) and to survey potential NDT methods for the detection of microshrink in superalloy castings. The discovery and acceptance of such an NDT method would probably also improve the reliability of turbine blades.

MATERIAL AND PROCEDURE

To accomplish the above objectives, bars of alloy 713C were cast at 2835°F with mold temperatures of 1800°F, 1900°F, and 2000°F. The purpose of this was to obtain a range of the quantity of microshrink present in the material. All bars were 1/2-inch diameter by 4 inches long. The bars were examined by X-ray radiography ultrasonics, density measurement, and metallography.

The photomicrographs are shown in Figures 1 through 3. Microshrink was distributed through the specimens, in some cases rather unevenly. The area percent microshrink in the specimens was measured by means of an automatic image analysis system. Since the locations having the greatest amount of microshrink probably had the greatest effect on properties, these locations were included in the microshrink measurements. Since the area percent microshrink in a transverse plane might well relate to properties, the area percent microshrink in elongated areas transverse to each specimen were measured. The approximate location of these areas, 24 mils by 410 mils, are given in Figures 1 through 3.

Round tensile specimens, 0.252-inch-gauge diameter, were machined and tested at 1000°F in the as-cast condition in accordance with Reference 2. This was the temperature in the region of the turbine blade failure.

RESULTS AND CONCLUSIONS

Investigation of the Effect of Microshrink on Tensile Properties

The radiographs of bars cast with mold temperatures of 1800°F, 1900°F, and 2000°F are shown in Figures 4 through 6. The radiographs showed a somewhat mottled appearance which was due to the crystal structure of the material. No microshrink was apparent in these radiographs. The ultrasonic method was unable to distinguish between grain boundaries, second phases, and microshrink. Hence, it also was unable to indicate whether microshrink was present or not.

1. *AMMRC Study of CH47C/T55 L11A Problem Areas: Fourth Stage Turbine Blade*. Army Materials and Mechanics Research Center, Letter Report, July 1974.
2. *Standard Methods of Tension Testing of Metallic Materials*. 1979 Annual Book of ASTM Standards, Part 10, ASTM, ANSI/ASTM E8-79.

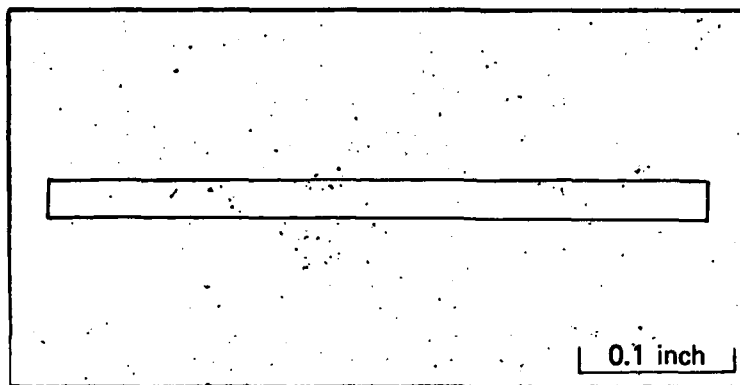


Figure 1. Microshrink in bar cast with mold temperature of 1800°F. The approximate area where measurement of area percent microshrink was made is indicated. Unetched. (Plate No. 4971)

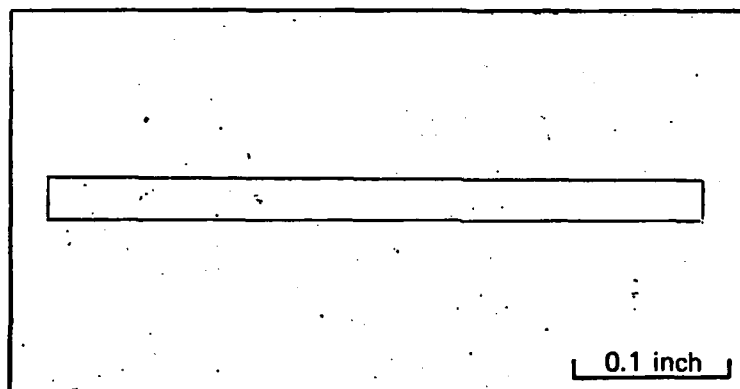


Figure 2. Microshrink in bar cast with mold temperature of 1900°F. The approximate area where measurement of area percent microshrink was made is indicated. Unetched. (Plate No. 4972)

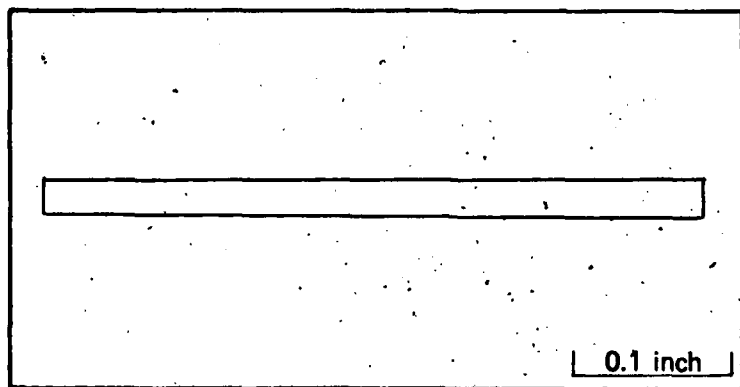


Figure 3. Microshrink in bar cast with mold temperature of 2000°F. The approximate area where measurement of area percent microshrink was made is indicated. Unetched. (Plate No. 4973)

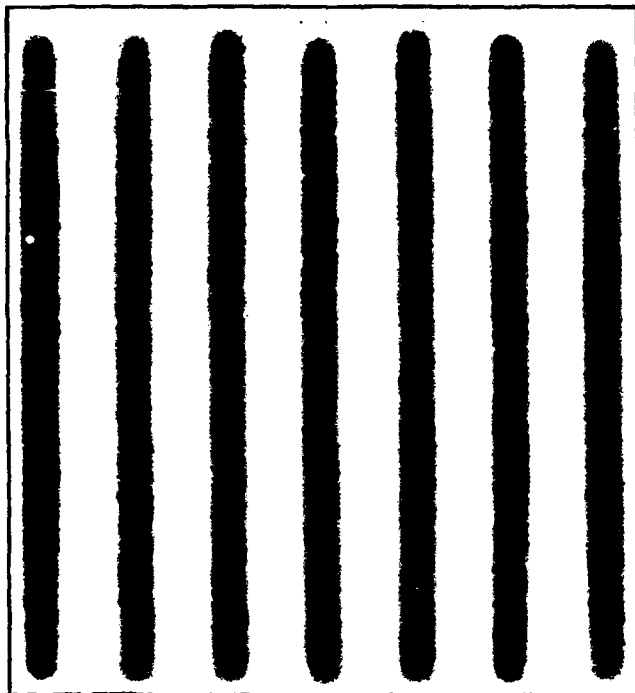


Figure 4. Radiograph of bars cast with mold temperature of 1800°F.

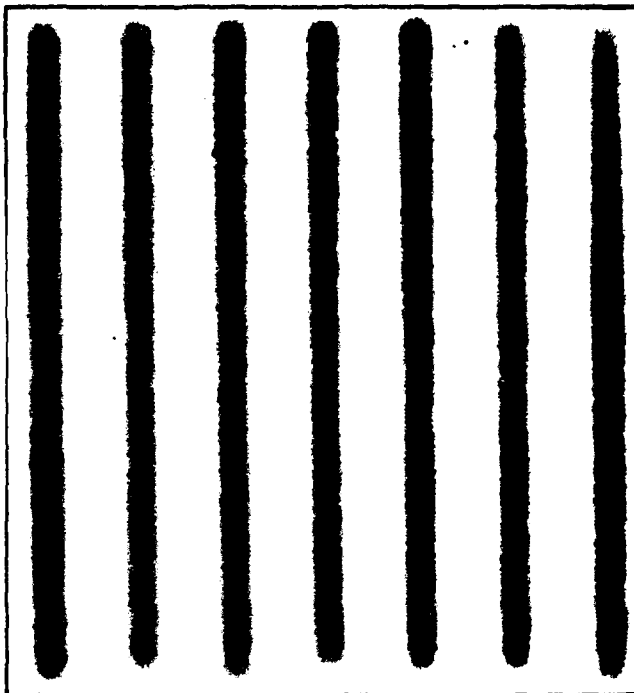


Figure 5. Radiograph of bars cast with mold temperature of 1900°F.

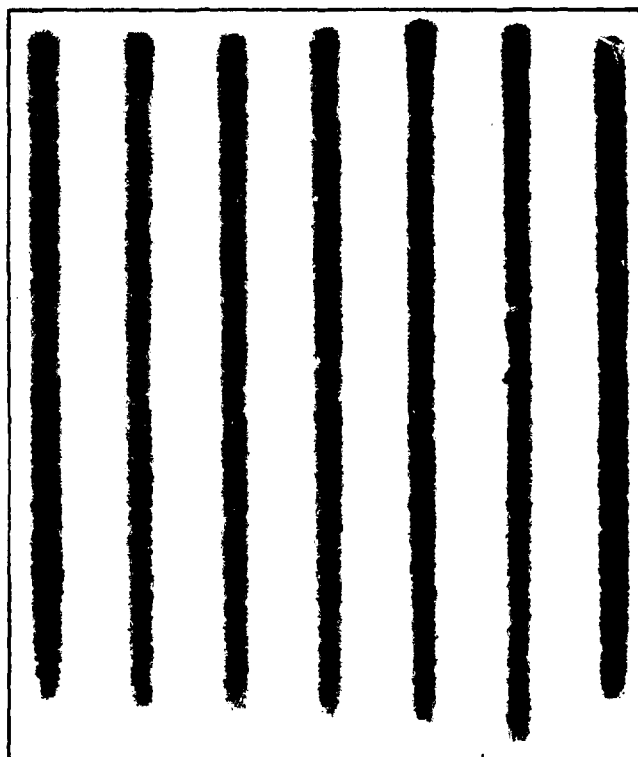


Figure 6. Radiograph of bars cast with mold temperature of 2000°F.

The mold temperatures and associated density measurements were as follows:

Mold Temp. (°F)	Density (g/cc)
1800	7.90
2000	7.92
Reported in Literature ³	7.91

Within the limits of experimental error, no microshrink was detected by density measurements.

The amount of microshrink measured as described in the Material and Procedure section of this report and the tensile properties at 1000°F are given in Table 1 and graphed in Figure 7.

The amount of microshrink did not have any significant effect on the strength and elongation. From the data, no conclusion could be drawn relative to the effect of microshrink on reduction of area.

With respect to the tensile properties measured, it did not appear necessary to control microshrink within the range studied. However, additional studies may be desirable, as described in the Recommendations, below.

Survey of Methods to Detect Microshrink Nondestructively

A large number of sources were utilized to obtain information on methods to measure microshrink. There were a number of possible nondestructive methods for detecting microshrink. These methods are given in the Appendix. In the case of radiographic methods, the sensitivity and thickness determine the minimum size of defect that can be detected. Since the maximum thickness of a blade of interest is about 150 mils, the minimum detectable defect size for radiographic methods was calculated as 150 mils times the sensitivity. This size may be used for purposes of comparing methods. The methods which appeared to be of the greatest potential value were selected. They are discussed below, in decreasing order of the minimum detectable shrinkage size.

Conventional X-ray radiography has a minimum detectable microshrink size of 3 mils (in a 150-mil section). The sensitivity is relatively low, but the method is well developed, and standards for the amount of microshrink are given in Reference 4. High definition X-ray radiography is done by means of a very small X-ray source. Radiation from this source passes through the object being radiographed to the film. Because of the very small size of the source, the definition of small features in the object is much improved. This method has a minimum detectable shrinkage size of 0.40 mil which is much less than the conventional X-ray, however, it is relatively expensive and slow. High sensitivity X-ray is done by using fine grained, high contrast film and optimizing process variables. The ability of the process to detect features which are small in the direction through the thickness is thereby much improved. High sensitivity X-ray has a minimum detectable shrinkage size of about 0.15 mil, an even smaller size, but further

3. Aerospace Structural Metals Handbook. Battelle Columbus Laboratories, v. 4, 1982, p. 1.

4. *Standard Reference Radiographs of Investment Steel Castings for Aerospace Applications*. 1978 Annual Book of ASTM Standards, Part II, ASTM E 192, p. 344.

development of the method would be required. Subthermal neutron, radiography has a minimum detectable shrinkage size of 0.05 mil, but once again, further development of the method would be required.

Based on the above information, methods for use and/or development to detect and measure microshrink may be selected.

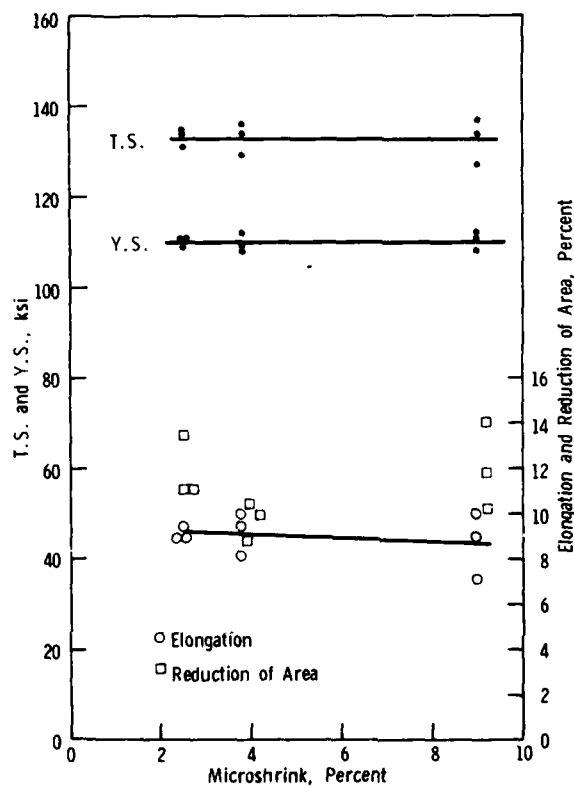


Figure 7. Tensile properties at 1000°F versus microshrink.

Table 1. PERCENT MICROSHRINK AND TENSILE PROPERTIES AT 1000°F

Mold Temp. (°F)	Micro-shrink (%)	Specimen	Yield Strength, 0.2% (ksi)	Tensile Strength (ksi)	Elongation (%)	R.A. (%)
2000	2.5	1	111	135	9.0	11.0
		2	109	134	9.5	13.4
		3	111	131	9.0	11.0
		Mean	110	133	9.2	11.8
1900	3.8	4	108	129	8.0	8.8
		5	109	134	9.5*	10.4*
		6	112	136	10.0	10.2
		Mean	110	133	9.2	9.8
1800	9.0	7	112	137	9.0	10.2
		8	111	127	7.0	11.8
		9	108	134	10.0	14.0
		Mean	110	133	8.7	12.0

*Fractured outside gage marks

RECOMMENDATIONS

Although microshrink did not appear to affect tensile properties significantly in the range studied. Consideration should be given to making an investigation of whether it effects other critical properties, such as fatigue and creep.

APPENDIX A. METHODS FOR DETECTING MICROSHRINK

Method	Sensitivity (Percent of Thickness)	Approximate Minimum Detect- able Shrinkage Size (mil)	Remarks	Reference
1. Scanning Laser Acoustical Micro- scope	--	a. 0.9 at 100 MHz b. 0.2 at 500 MHz	Specimens several mm thick are readily analyzed. Thickness of specimen will be less than above. May be less expensive than X-ray. Shows internal structure. The smallest defect that can be detected is about one-half of the wavelength, due to dif- fraction effects. As frequency increases, acoustic attenuation increases, and depth of detection decreases.	*
2. Conventional X-Ray Radiography	2.0	3.0	Relatively low sensitivity. Standards for sponge shrinkage are available in Reference 4.	†
3. High Sensitivity X-Ray Radiography	0.1	0.15	Some process development required.	†
4. High Definition X-Ray Radiography	--	0.40	Relatively expensive and slow. Thick- ness limit: 315 mils steel equivalent.	**
5. Eddy Current	NA	1.0	Surface defects only.	
6. Subthermal Neutron Radiography	--	0.05	Complements X-ray. Development of method required.	††
7. Ultrasonic B-Scan	--	78.0	Specimen must have suitable shape.	5
8. Acoustic Holography	--	40.0	Commercially available.	5
9. Quantitative Ultra- sonic Tomographic Imaging	--	20.0	--	6

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††Frank Patricelli, Science Applications, Inc., La Jolla, CA.

5. *Advanced Techniques for Acoustic Imaging*. NTIAC Newsletter, Nondestructive Testing Information and Analysis Center, v. 7, no. 3, August 1979.

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THE DETECTION OF MICROSHRINK -
Perry R. Smoot

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Technical Report AMMRC TR 84-43, November 1984, 9 pp -
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High temperature alloys
Casting
Metallography

The unknown effects of microshrink on the tensile properties of cast nickel-base alloys were investigated. The objectives of this investigation were to study the effect of microshrink on the tensile properties of alloy 713C and to find nondestructive methods of detecting microshrink at any significant level. Alloy bars were cast, the microshrinkage was measured metallographically, and tensile tests were run at 1000°F. A large number of sources were searched for information on methods to detect microshrink. Within the range of 2.5% to 9%, measured in the local area having the greatest amount present, microshrink did not have any significant effect on tensile properties. A number of methods to detect microshrink nondestructively were found, but those other than conventional X-ray radiography would require development. The effect of microshrink on fatigue and creep properties was not investigated. Consideration should be given to making such an investigation of these effects.

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